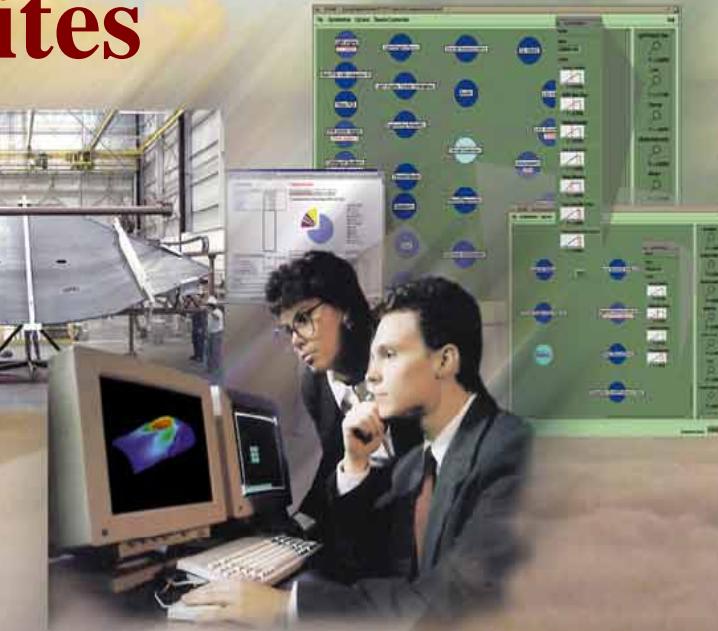


# Accelerated Insertion of Materials - Composites



*Presented at Mil-Hdbk-17 Forum*

by Tony Caiazzo  
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26 February 2003



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# AIM-C Alignment Tool

*The objective of the AIM-C Program is to provide concepts, an approach, and tools that can accelerate the insertion of composite materials into DoD products*

## AIM-C Will Accomplish This Three Ways

**Methodology** - *We will evaluate the historical roadblocks to effective implementation of composites and offer a process or protocol to eliminate these roadblocks and a strategy to expand the use of the systems and processes developed.*

**Product Development** - *We will develop a software tool, resident and accessible through the Internet that will allow rapid evaluation of composite materials for various applications.*

**Demonstration/Validation** - *We will provide a mechanism for acceptance by primary users of the system and validation by those responsible for certification of the applications in which the new materials may be used.*

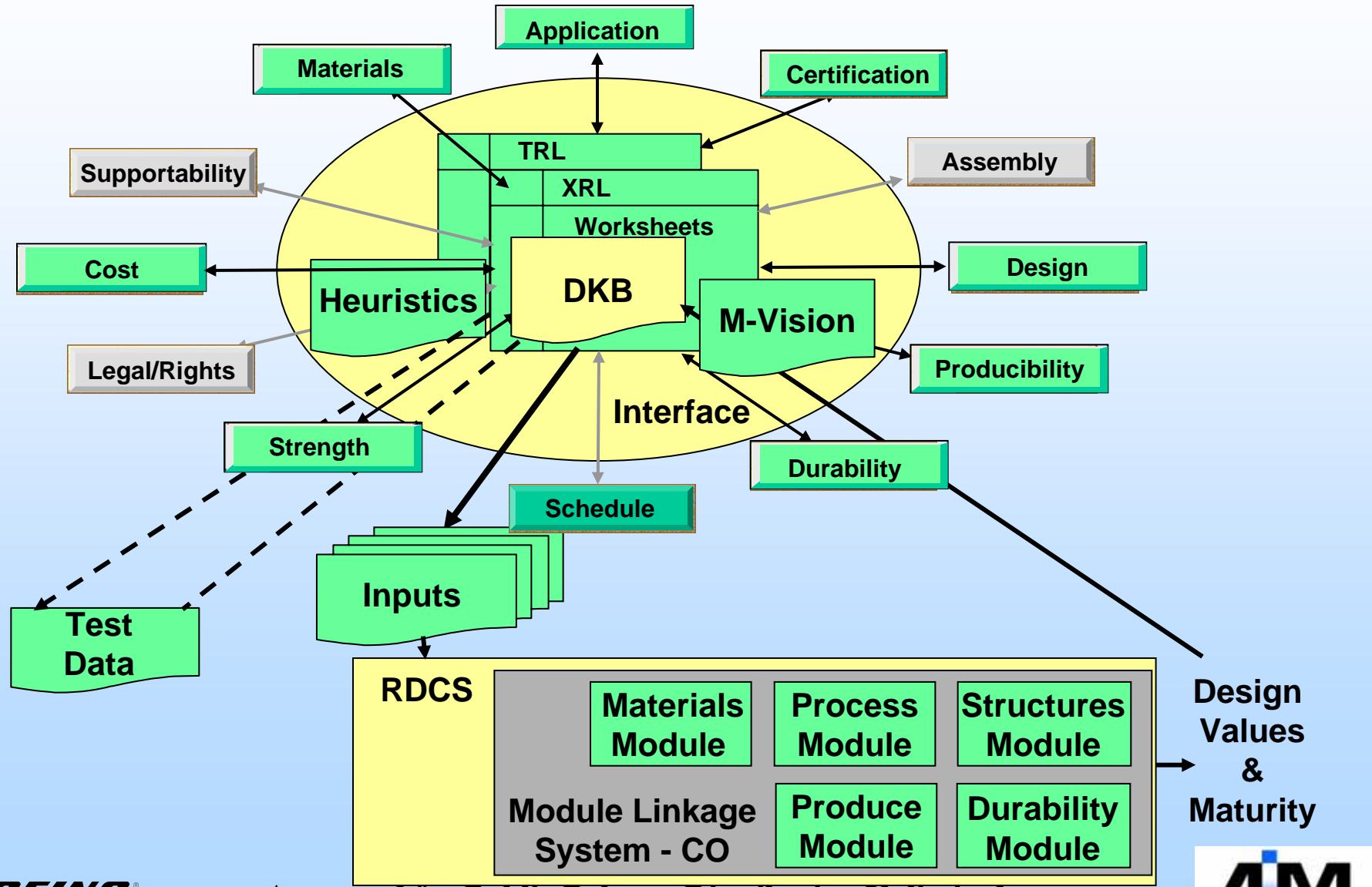


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# AIM-C System Vision

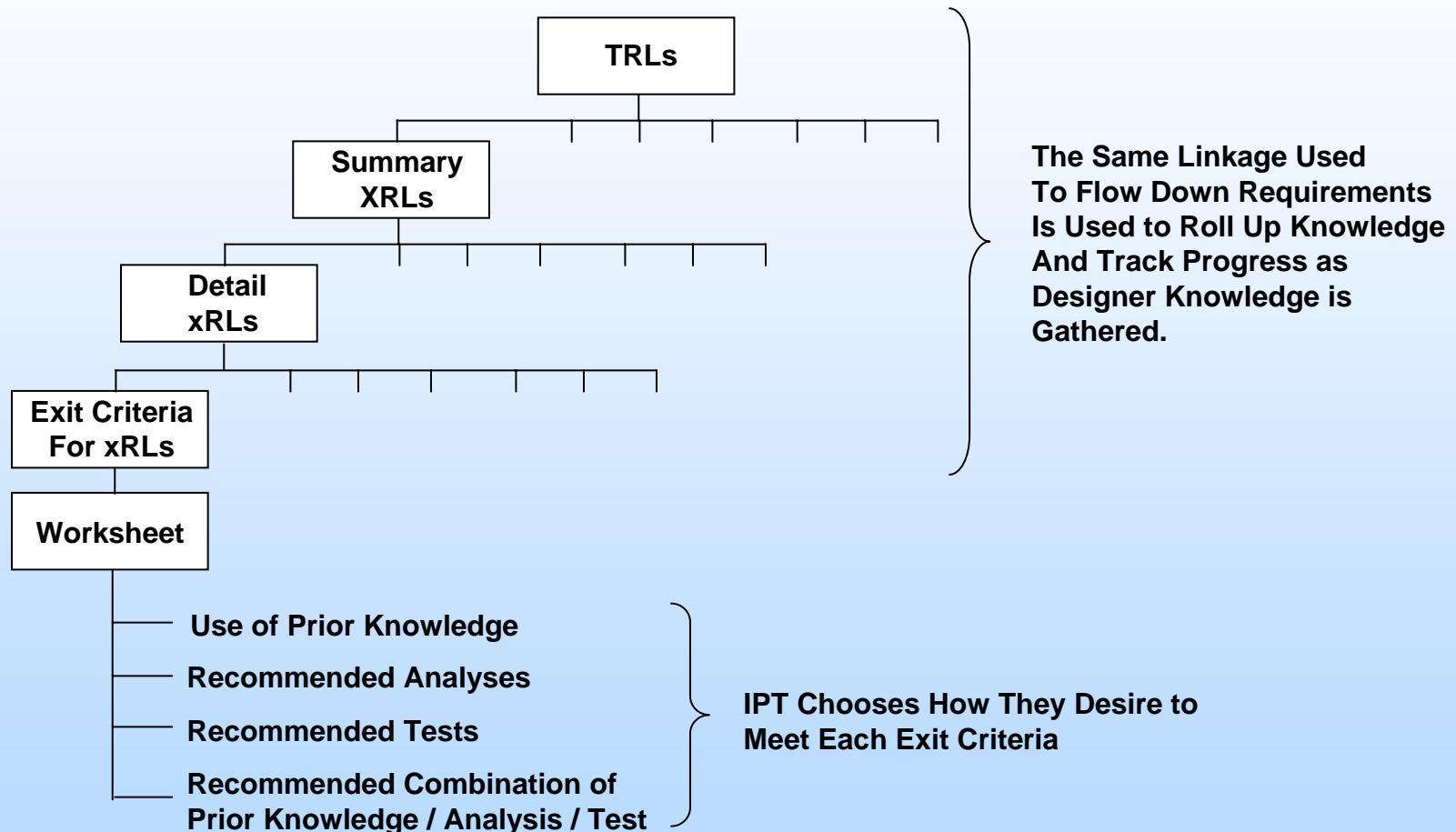


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## *AIM Methodology Becomes a Requirements Flow Down and a Completion Roll Up*



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# AIM-C Transition Plan

February 2001

February 2002

February 2003

February 2004

AIM Product  
Development

AIM Product  
Verification

AIM Product  
Demonstration

AIM Product  
Refinement

AIM Product  
Validation

AIM Product  
Implementation

Basic Program

Optional Program

Phase II

Customer Team

Design Team

Certification Team

Implementation Team

Commercialization Team

**Customer Team** – To ensure that the product meets the needs of the funding agents

**Design Team** – To ensure acceptance among users in industry

**Certification Team** – To ensure acceptance among the certification agents for structures

**Implementation Team** – To ensure acceptance among the user community

**“Commercialization” Team** – To ensure support of users

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## AIM-C Certification Team



Agency	Integration	Structures	Materials	Producibility
Boeing	Charley Saff	Eric Cregger	Pete George	John Griffith
Navy	Don Polakovics	Dave Barrett	Kathy Nesmith	Steve Claus
Air Force	Tim Jennewine	Dick Holzwarth	Katie Thorp	Bob Reifenberg
FAA	Curt Davies	Larry Ilcewicz	David Swartz	Dave Ostrodka
Army	Mark Smith	Jon Schuck	Marc Portanova	Steve Smith
NASA	Mark Shuart	Jim Starnes	Tom Gates	Tom Freeman

***To Insure That the Methodology, Verification, and System Validation We Do Satisfies Certifying Agencies***



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AIM-C Main Menu - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Back  Home  Search  Favorites  History

Address  http://144.117.90.50:8080/AIM-C/V\_0.0.1/aim.jsp Go Links

# Conceptual Display

## AIM-C Main Menu

### Designer's Knowledge Base

#### Coefficient of Thermal Expansion

Thermal Expansion Properties are Reported as a Function of the State Properties Degree of Cure, Temperature, and Moisture Content

Resin: Cytec 977-

Fiber: Hexcel IM7

State Variables

Degree of Cure: 0.84

Temperature: 70 F

Moisture Content: Not Available

Layup Definition: 0/90, +/-0

Calculation Method: CAT

Export to CSV  go

Link to Model  go

Property To Display: Alpha xx

1. Hexcel IM7  
2. Hexcel AS4

1. 0/90, +/-0  
2. Carpet Plot  
3. Unidirectional  
4. Custom  
Defined  
1. CAT (Linked  
Modules  
2. From DataBase

1. Alpha x vs. Layup  
2. Alpha y vs. Layup  
3. Alpha z vs. Layup  
4. Alpha x vs. T at a Given Theta  
5. Alpha y vs. T at a Given Theta  
6. Alpha z vs. T at a Given Theta

(a) AIM-C Integration 01

θ (deg)

α<sub>xx</sub> (10<sup>-6</sup>/K)

30  
20  
10  
0  
-10

0 20 40 60 80

Alpha Minus Version [Help](#)

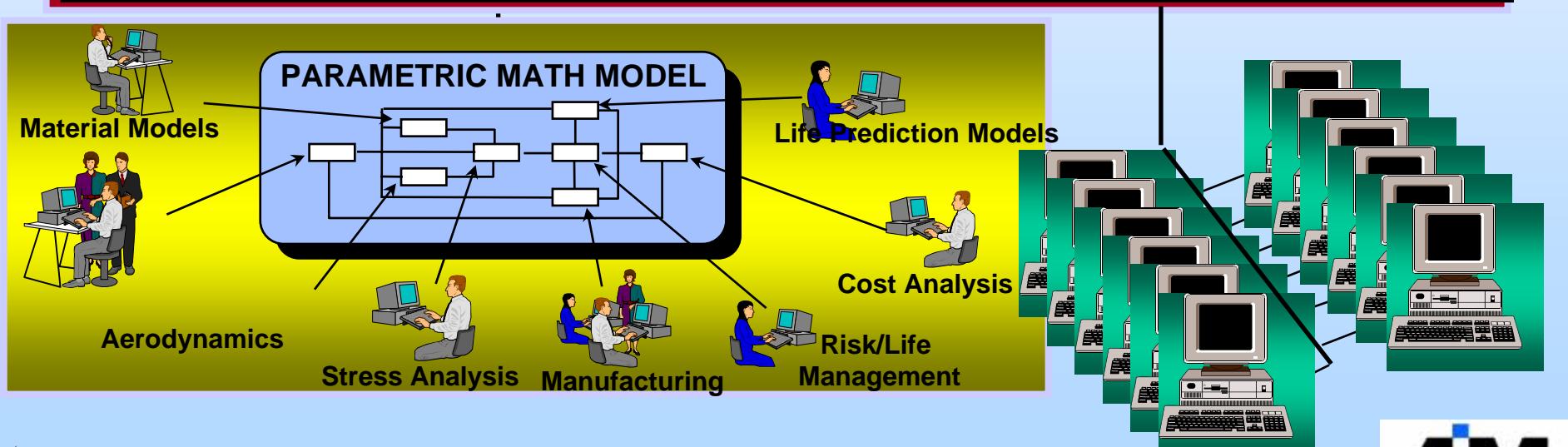
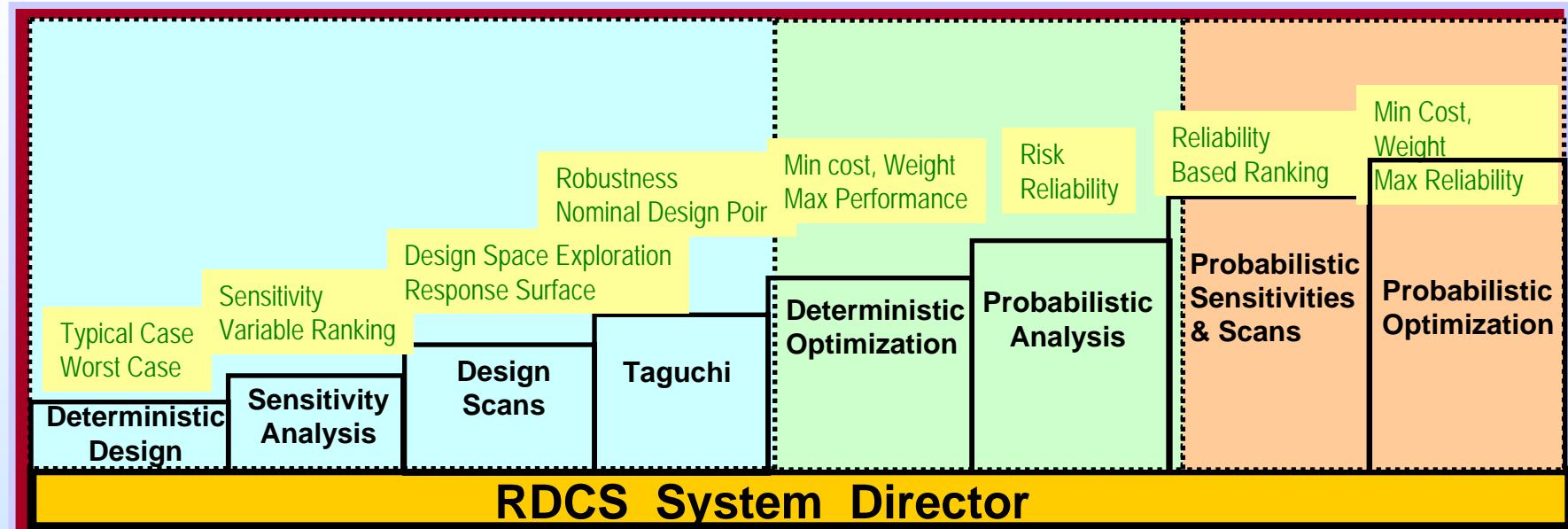
Boeing | Navair | DARPA | CYTEC | NorthropGrumman | MIT | Standford U | MSC | UBC

Start  Internet  8:30 AM

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# Robust Design Computational System



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# RDCS Edge of Flange Disbond Study

## The Problem

### Application Objective

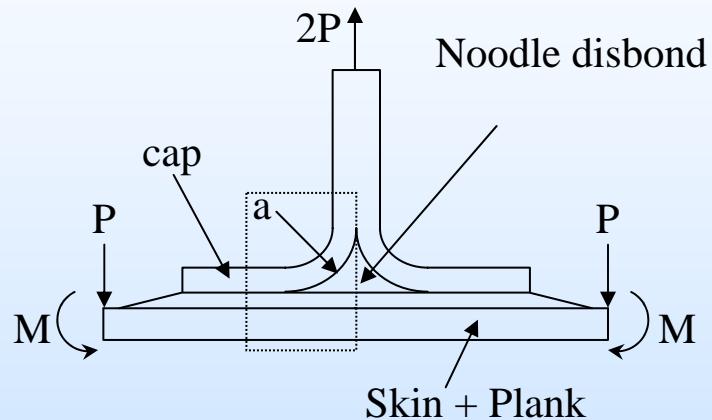
- Investigate the effect of skin-stringer panel geometric parameters on maximum moment at the flange and margin of safety for stringer pull-off
- To aid in the selection of appropriate stiffener geometry and spacing

### High Level Description

- **Design variables:** Skin Thickness, Flange Thickness, Stiffener Height, Total Flange Width
- **Response Variables:** Maximum Flange Moment, Pull-off Margin
- **Solvers/Methods:** RDCS, ANSYS/LEFM

### Solution Scope

- **RDCS:** Sensitivity analysis, Factorial Design Space Explorations
- **ANSYS:** Static non-linear large deflection analysis
- **Solution Cases:** 81 Large Scale FEM Solutions



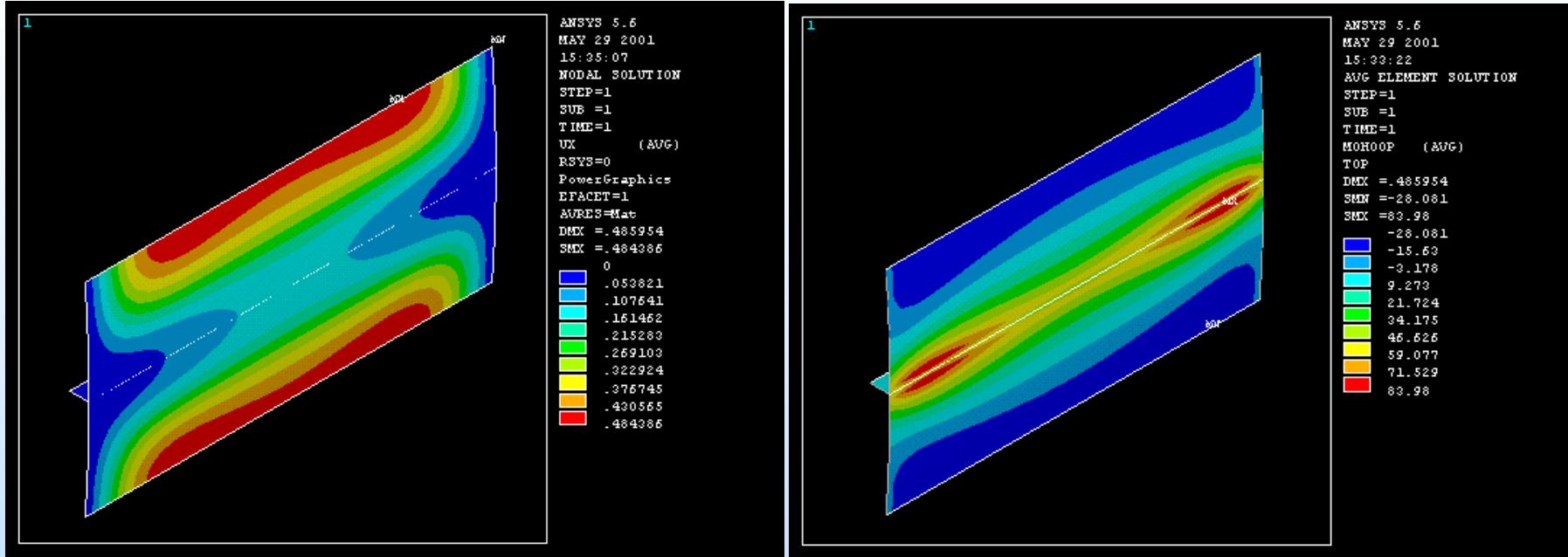
### RDCS Application Benefits

- Rapid factorial design calculations for external ANOVA study and response surface with significant cycle time reduction
- ANOVA helps identify critical factors and interactions
- Accurate surrogate response surface model helps simplify the design process



# RDCS Edge of Flange Disbond Study

## The Problem



Internal Pressure (or postbuckling) create large pillowing deflections between stringers

These deflections create high moments at the skin-to-stringer bondline. The loads don't vary tremendously along the length – can be analyzed as a 2D problem using the maximum loads (conservative)



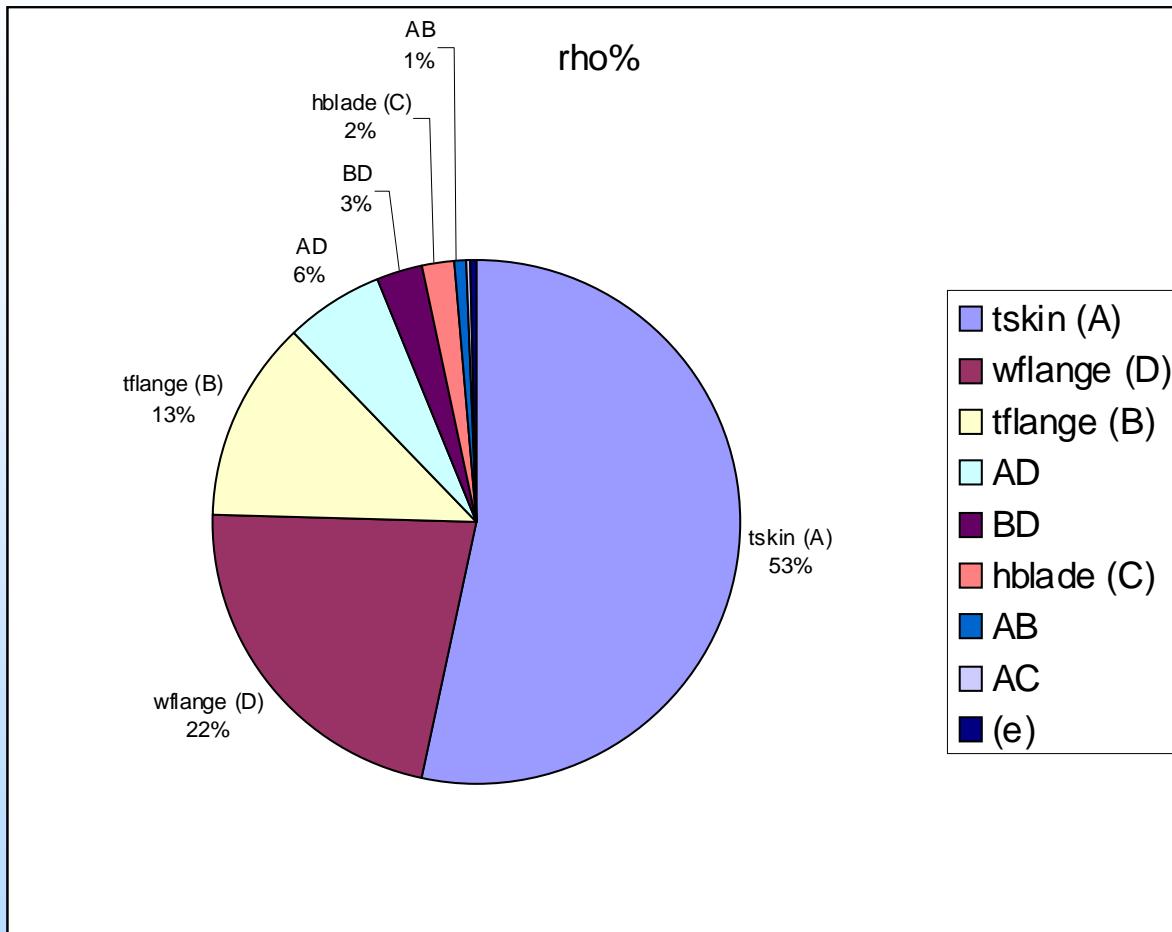
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# RDCS Edge of Flange Disbond Study

## ANOVA Results



The major influences are skin thickness, flange width, flange thickness, and their interactions



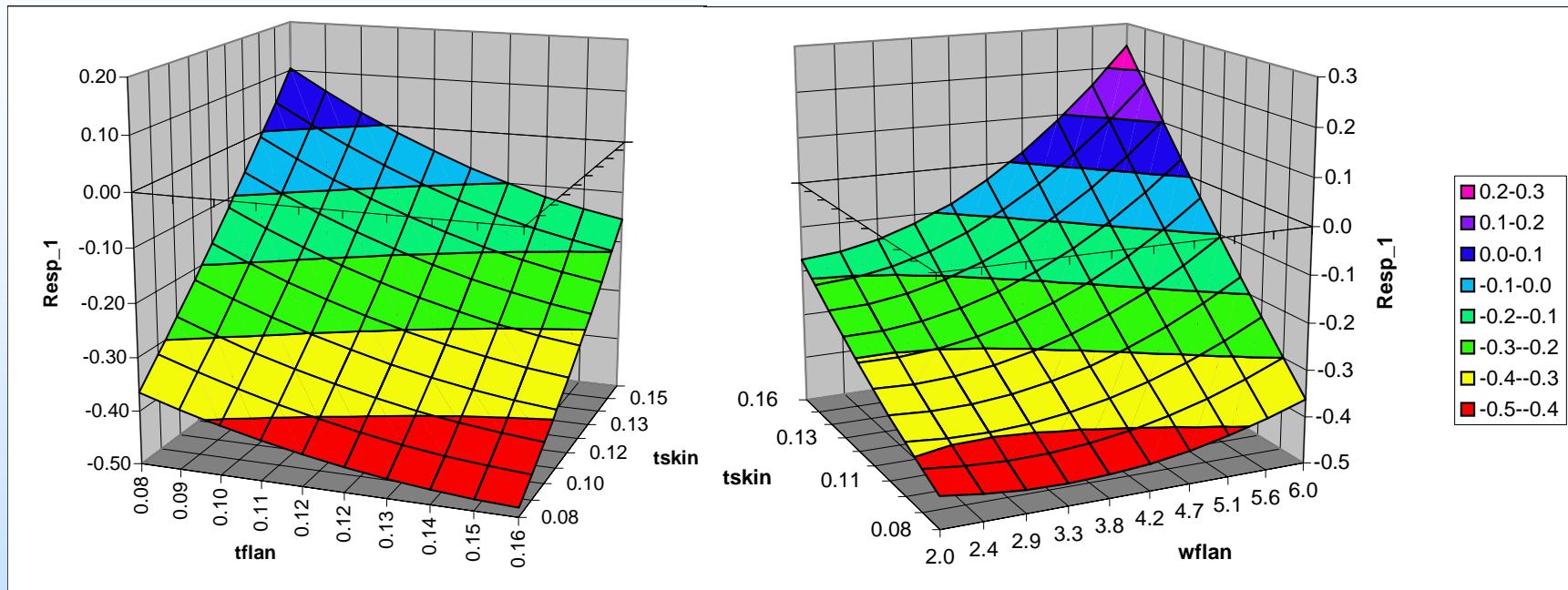
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# RDCS Edge of Flange Disbond Study

## Interaction Results



- Best edge-of-flange peel margin of safety is when skin is thick and flange is thin
- Flange width has a much greater effect on the margin when skins are thick. The effect is highly nonlinear.

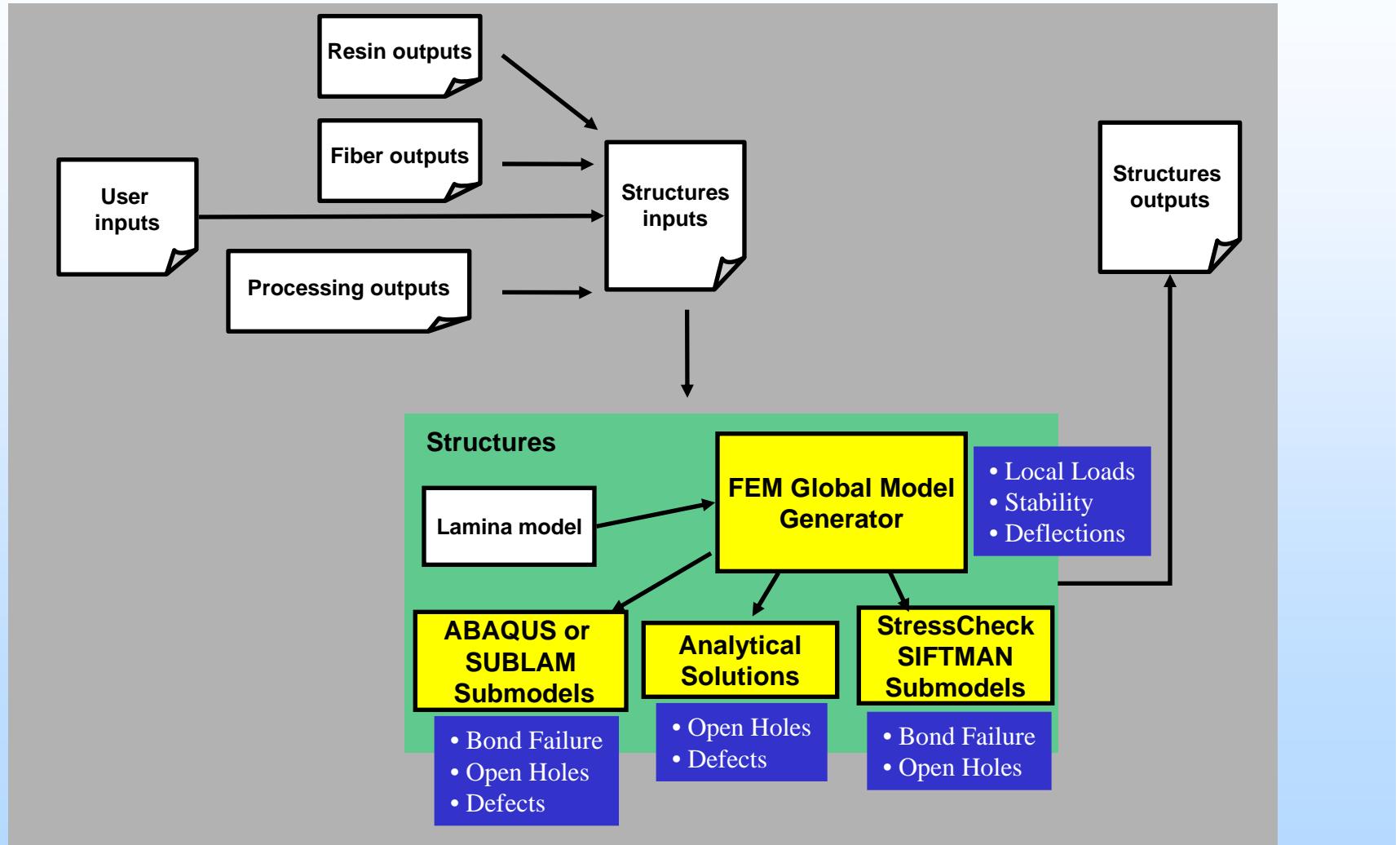


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# Schematic of Design/Analysis Framework

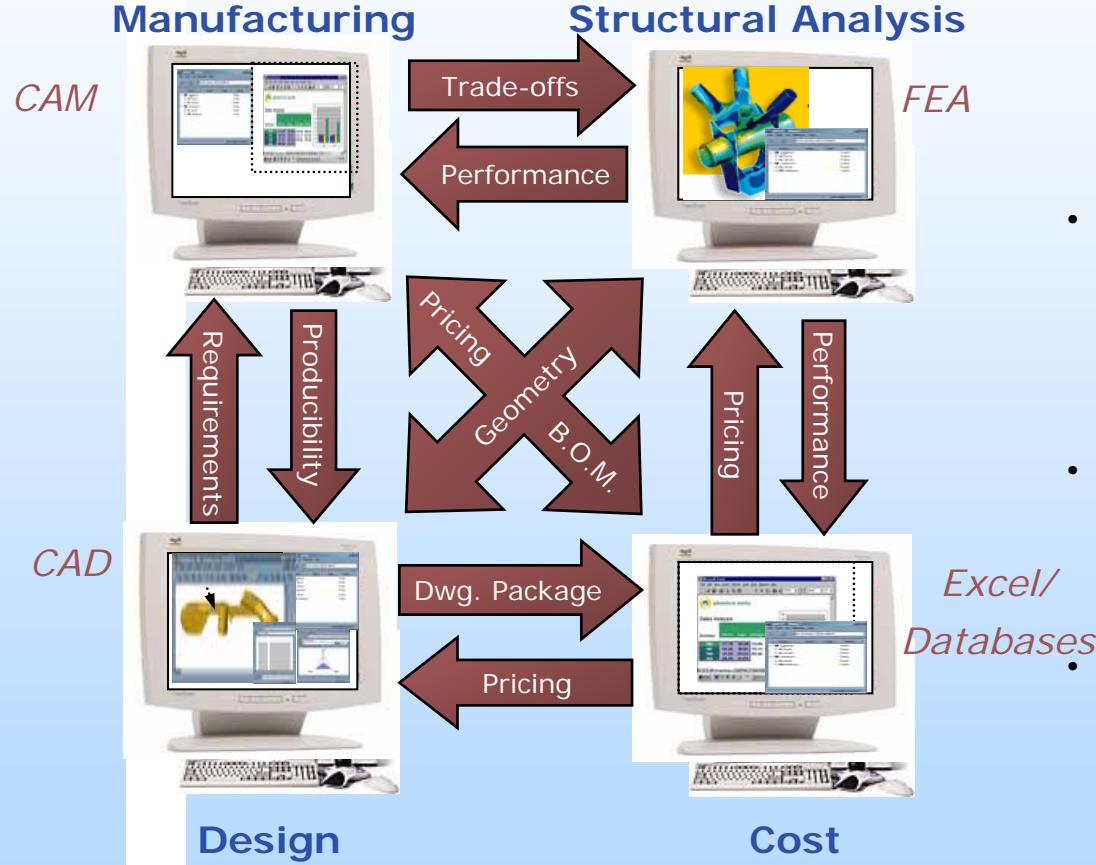
## Long term Strategy





# The Oculus Integration System

## *CO<sup>TM</sup>: A Plug & Play Modeling Environment*



- **Integrates Data and Software Applications on-the-fly**
  - Drag & Drop, Plug & Play
  - Simple to create, modify, manage, maintain
- **Enables Real-time data sharing between applications**
  - Secure
  - Controlled
  - Intra/Internet
- **Platform Independent**
  - Distributed
  - Neutral to Platforms and Applications
- **Increases Value of Previous Investments**
  - Software
  - Hardware
  - Networks



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# Oculus Models

Currently 3 models on MSC's Engine

Name	Value	Units	Policy	Access
Variables			Private	○
Lamina_Batch			Private	○
Laminate_MaxStrain			Private	○
Dashboards			View	○
Problem Definition			Public	○
Process Variables			Public	○
Fiber Props @ Operating Temp			Public	○
Resin Props @ Operating Temp			Public	○
SIFT Properties			Public	○
Maximum Strain Failure Criteria			Public	○
Hashin Failure Criteria			Public	○
Phase Average Failure Criteria			Public	○
Run	Lamina_Ba...		Execute	○
Laminate Relations			Private	○
Lamina Relations			Private	○
Lamina Variables			Private	○
Laminate Variables			Private	○
Laminate_Hashin			Private	○
Laminate_PhaseAvg			Private	○



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# Oculus Dashboards

The image displays two windows side-by-side, both titled "Problem Definition - CO".

**Left Window (Input Dashboard):**

- Problem Definition:** Public
- Lamina method:** 1 unitless
- Operating Temp:** 70 degree fahrenheit
- z offset:** 0.000E0
- Number of plies:** 8 unitless
- Layup Info:** (Material ID (1), Thickness)

	0	1	2
0	1	0.008	45
1	1	0.008	0.000E0
2	1	0.008	-45
3	1	0.008	90
4	1	0.008	90
5	1	0.008	-45
6	1	0.008	0.000E0
7	1	0.008	90
- # of Load Sets:** 3 unitless
- Open Hole Info:** (Material ID (1), Thickness)

	0	1	2	3	4
0	0.125	640	0.000E0	0.000E0	0.160
1	0.125	640	0.000E0	0.000E0	0.160
2	0.125	640	0.000E0	0.000E0	0.160
3	0.000E0	0.000E0	0.000E0	0.000E0	0.000E0
- Run**

**Right Window (Output Dashboard):**

- Hashin Failure Criteria - CO:** Public
- Theta = 0 degrees:**

failedPlyMatrix1	1	unitless	loadFactorMatrix1	44.857	unitless
failedPlyFirstFiber1	4	unitless	loadFactorFirstFiber1	32.560	unitless
failedPlyLastFiber1	7	unitless	loadFactorLastFiber1	104.658	unitless
- Theta = 45 degrees:**

failedPlyMatrix2	4	unitless	loadFactorMatrix2	7.459	unitless
failedPlyFirstFiber2	3	unitless	loadFactorFirstFiber2	9.915	unitless
failedPlyLastFiber2	1	unitless	loadFactorLastFiber2	1066.754	unitless
- Theta = 90 degrees:**

failedPlyMatrix3	4	unitless	loadFactorMatrix3	4.490	unitless
failedPlyFirstFiber3	1	unitless	loadFactorFirstFiber3	7.378	unitless
failedPlyLastFiber3	8	unitless	loadFactorLastFiber3	88.083	unitless

**Output dashboard:**  
Hashin failure info for OHT

Taskbar icons: Start, Eudora, Yahoo!, Exceed, Problem D..., Hashin Fa..., Microsoft P..., 9:57 AM



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## Structures - Hat Stiffened Panel (HSP) Design/Analysis Procedure

- HSP is a large-scale, complex, detailed design problem  
Draw on multiple AIM-C modules.
- Accurate results require very fine grid mesh or small element sizes  
Problem is too large in scale to model with one finite element  
Thus, a combination of global and local models will be used.
- Submodeling or local modeling capture design details and mfg. defects  
Submodels are finely meshed cutouts of the global model.  
Global Model results feed the submodels



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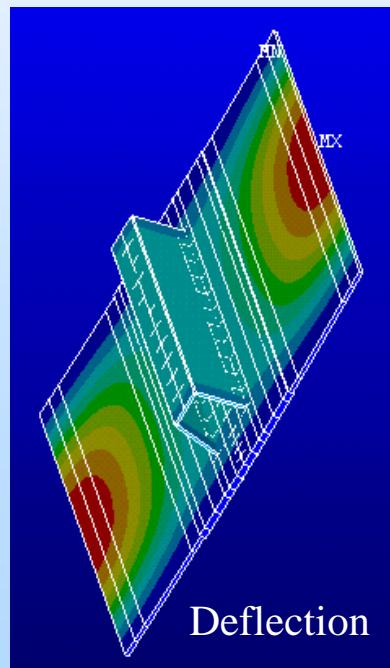
## Parametric Global Structures Module

What do you gain from the Global Models?

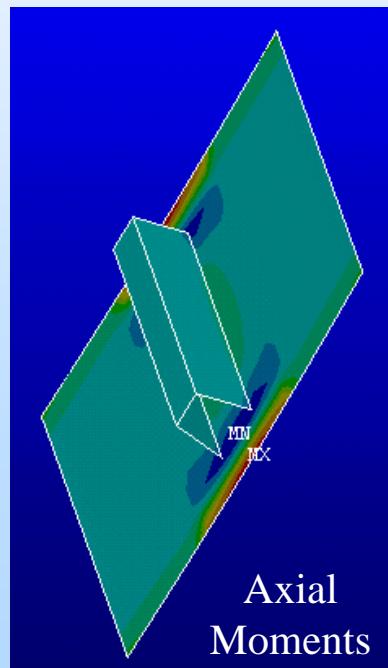
- Accurate Load Distribution – Failures depend on correct local loads
- Identification of Local Model Requirements
- Easy assessment of Multiple Load Cases
- Rapid Design Iteration – Ability to perform quick geometry trades
- Assessment of Global Failure Modes – Stability, Deflection

How do they work? Demonstration using a simple one-bay hat model in ANSYS

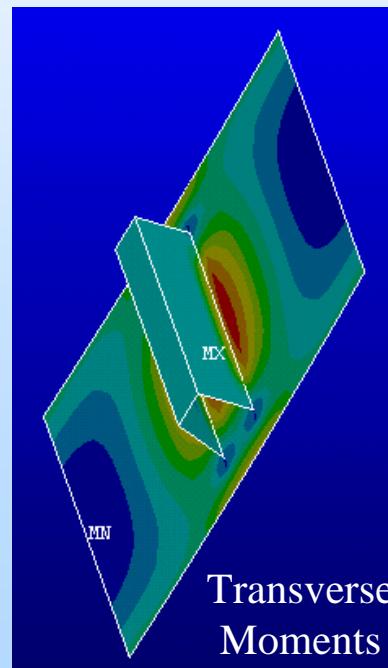
- Model and run a baseline...Hat under pressure (Linear)



Deflection



Axial  
Moments



Transverse  
Moments



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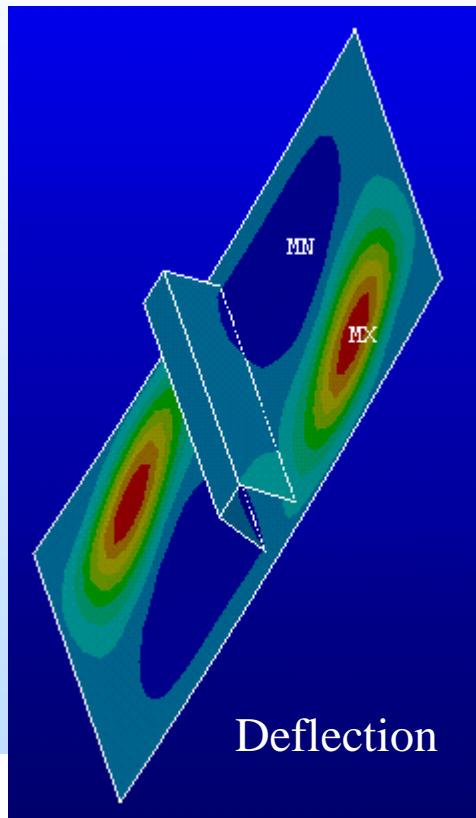




## Parametric Global Structures Module Demonstration

### Global and Local Failure Modes

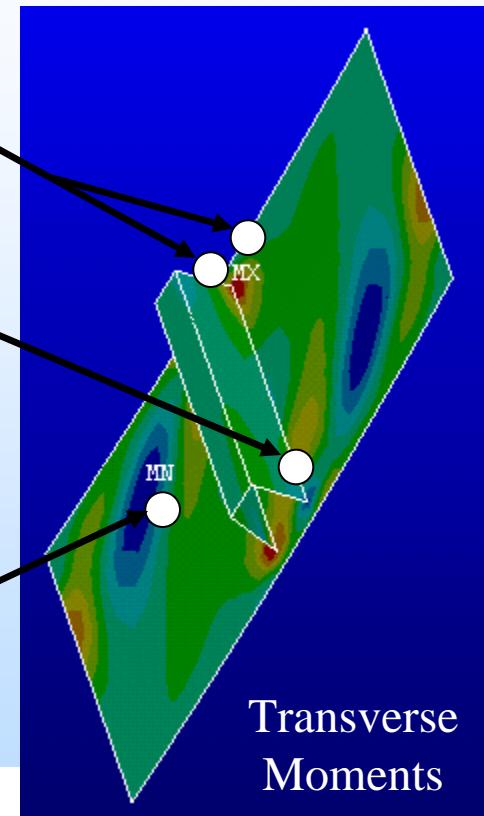
Another load case...Hat under in-plane shear (2500 $\mu\epsilon$ )  
(Nonlinear Large Deflection Solution)



Local Bondline  
Failure at Noodle  
Or Edge-of-Flange?

Radius Bending or  
Bow Wave Defect  
Failure?

OHC Strain  
Exceeded?



Transverse  
Moments

- Not buckled yet, but significant bending due to the eccentricity of the stiffener is beginning to form the first buckling mode shape. Max deflection is 0.034". Okay for Aero?
- Identify local model requirements.



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# Local Models

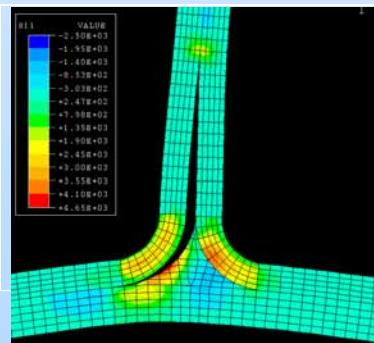
## Design Details

Local Models are used to perform detailed analysis in an area of interest, usually  
A potential failure location – often an area of high loading near a structural discontinuity

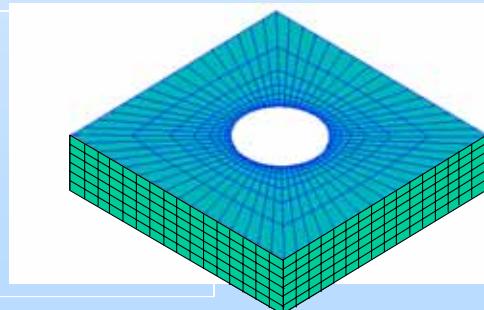
Two kinds of Local Models:

1. Design Details – a designed-in structural feature (e.g., Open Hole, Edge of Flange)
2. Mfg. Defect – an undesired “feature” produced as a side-effect of the manufacturing process (e.g., waviness, delamination, porosity)

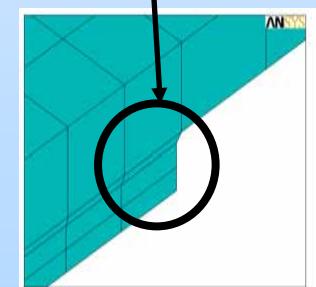
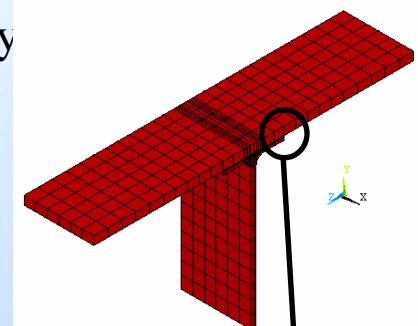
Local Models for Design Details:



“Noodle” Models



Open Hole Models



Edge-of-Flange Models



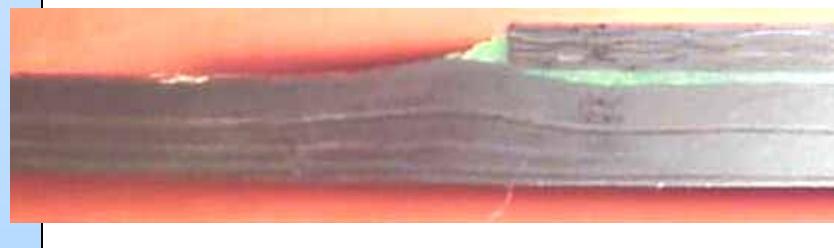
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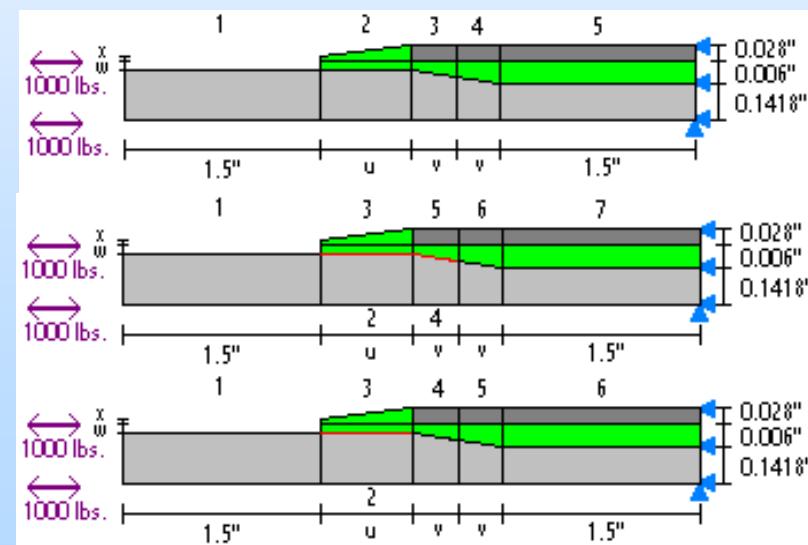


# Bow Wave Defect Analysis Using SUBLAM Linked to RDCS

- SUBLAM was incorporated into RDCS to demonstrate the concept of creating a suite of “defect analysis handbooks” to be inserted in the AIM-C CAT.**
- Full factorial design space scans were conducted to compute the sensitivity of local stresses and energy release rates under tensile and compressive loads to four geometric variables.**



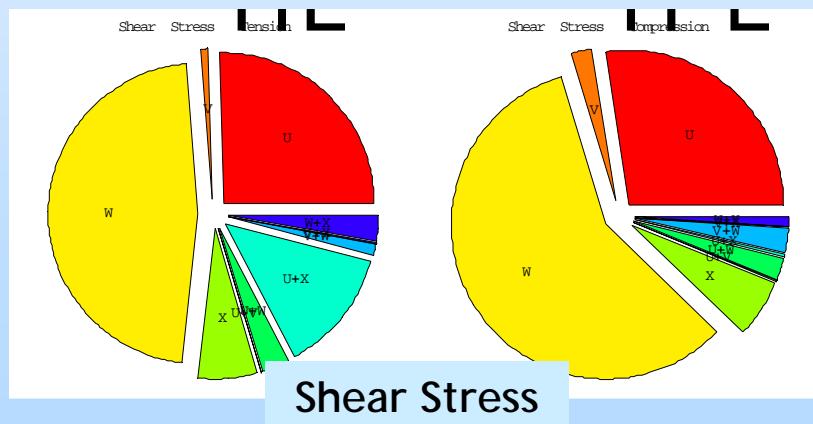
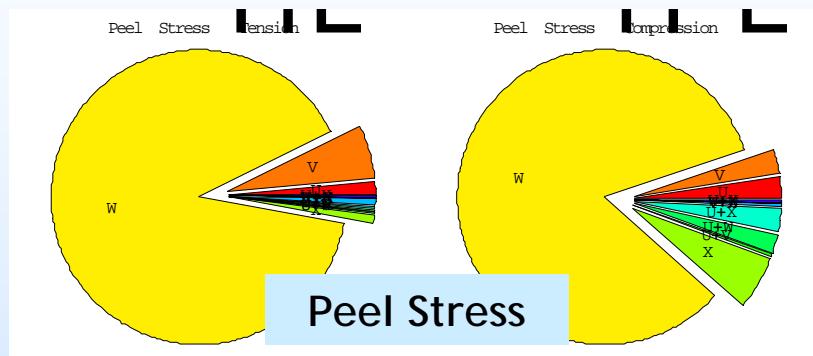
	Variable	Lower Limit	Center Value	Upper Limit
$u$	Resin pool length	0.05"	0.175"	0.3"
$v$	Bow-wave length	0.05"	0.125"	0.2"
$w$	Adhesive thickness	0.0005"	0.00325"	0.006"
$x$	Resin pool height	0.0005"	0.01425"	0.028"





# Bow Wave Defect Analysis – Sample Results

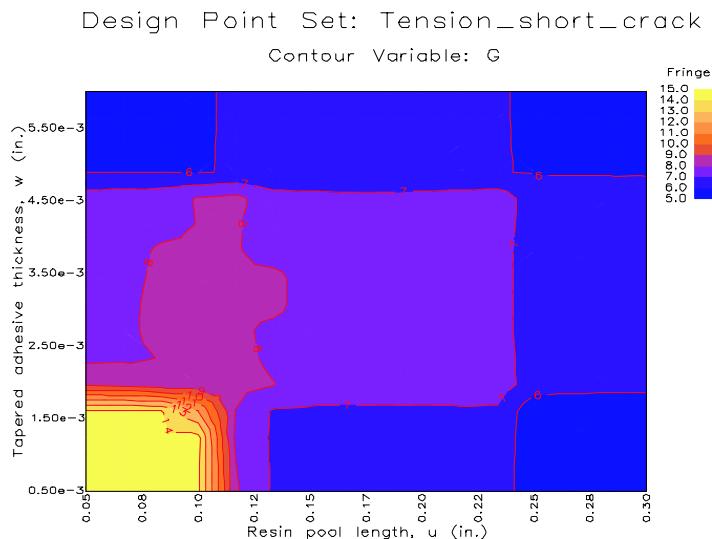
- Peel and shear stresses driven by adhesive thickness and resin pool length.
- Relative contributions depend only slightly on whether load is tensile or compressive.
- Some significant two-way interactions for shear stress, viz., resin pool length and height.
- Bow wave length not a big driver for range studied.



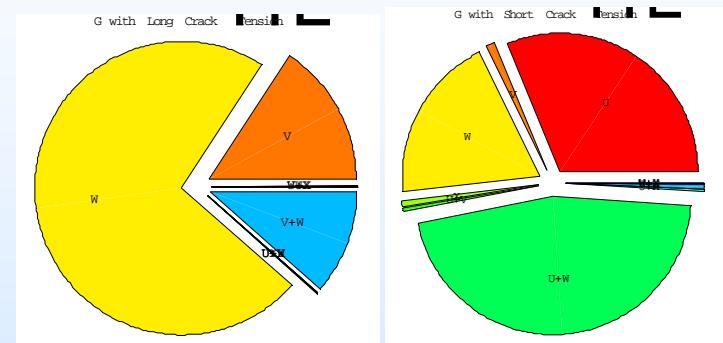


# Bow Wave Defect Analysis – Sample Results

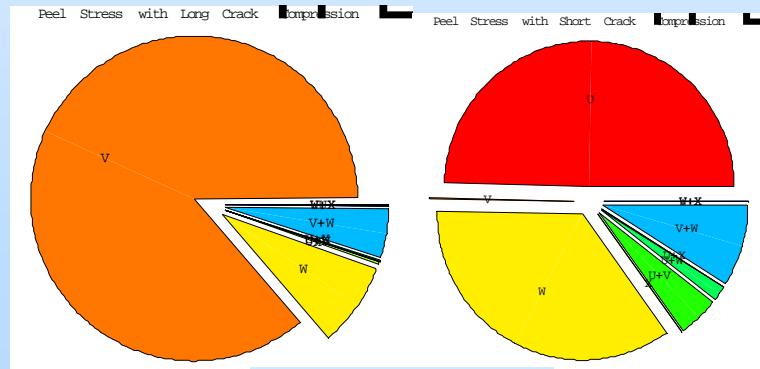
- Contributions to ERR (G) strongly dependent on whether load is tensile or compressive and initial crack (defect) size.



G (in-lbs/in<sup>2</sup>) for tensile load as a function of initial defect size and adhesive thickness.



Tension



Compression